Supersonic Particle Deposition (Cold Spray)

Phillip F. Leyman

US Army Research Laboratory
Weapons & Materials Research Directorate

Presented at HCAT Program Review Meeting
January 26, 2006

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **26 JAN 2006**	2. REPORT TYPE	3. DATES COVERED **00-00-2006 to 00-00-2006**
4. TITLE AND SUBTITLE **Supersonic Particle Deposition (Cold Spray)**		5a. CONTRACT NUMBER
		5b. GRANT NUMBER
		5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER
		5e. TASK NUMBER
		5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **U. S. Army Research Laboratory,Weapons & Materials Research Directorate,Aberdeen Proving Ground,MD,21005**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S)
		11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
26th Replacement of Hard Chrome and Cadmium Plating Program Review Meeting, January 24-26, 2006, San Diego, CA. Sponsored by SERDP/ESTCP.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**28**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

Cold Spray Center of Excellence at the US Army Research Laboratory (ARL)

Aberdeen Proving Ground, MD 21005-5069

ARL Cold Spray Research Team

Victor Champagne	Team Lead/Materials	(410) 306-0822
Phillip Leyman	Process Engineer	(410) 306-0818
Dr. Dennis Helfritch	Process Engineer	(410) 306-1928
Dr. Andrew Davis	Materials Engineer	(410) 306-0808
Mathew McCarry	Process Technician	(410) 306-2026
Dr. William DeRosset	Modeling/Simulation	(410) 306-0816

Cold Spray Briefing Objectives

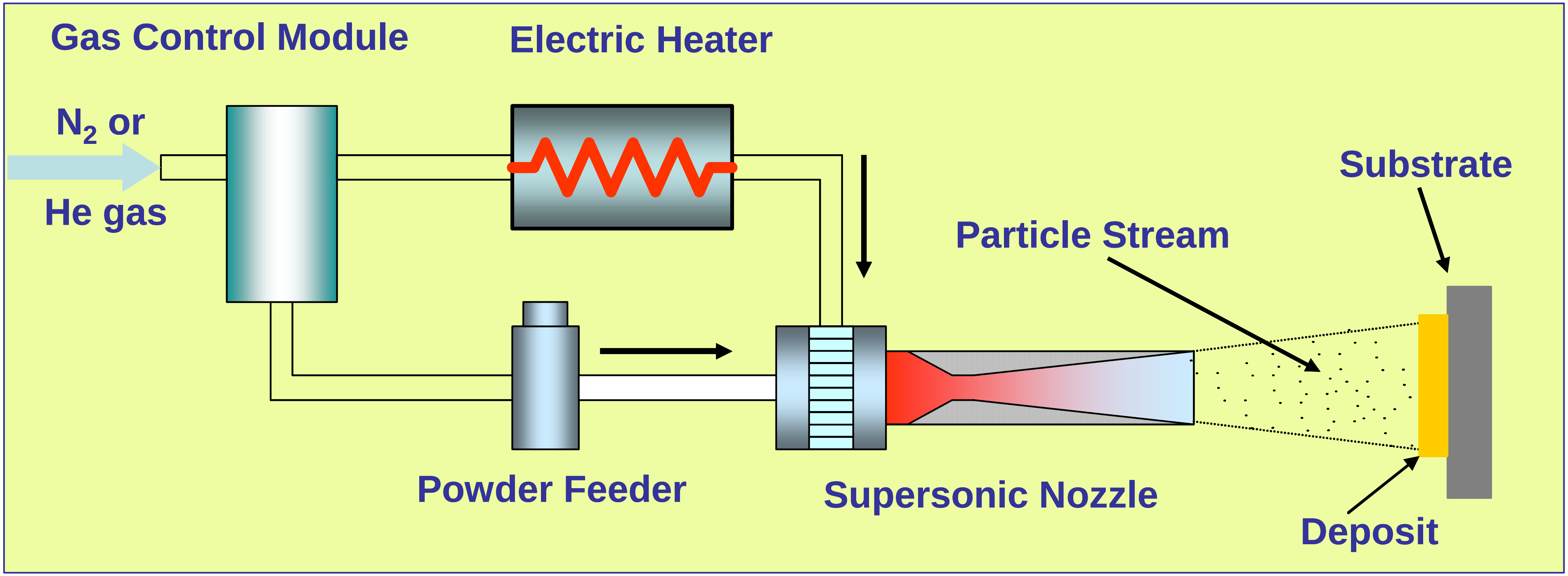
- Overview of ARL Cold Spray Efforts
- Discuss ARL Capabilities and Advantages of Cold Spray
- Present Three Applications of Cold Spray Being Developed at ARL
    - EMI Shielding for HMMWV Electronics Shelter
    - Wear and Corrosion Protection for Rotorcraft Mg Housings
    - Electromagnetic Gun Rails

ARL Cold Spray Customer & Research Programs

Customer/Collaborator	Application
•Defense Science Technology Organization-Australia	Corrosion Protection
•National Center for Manufacturing Sciences-MI	Corrosion Protection
•ESTCP-NRL-NADEP-AMCOM-PennState-Sikorsky	Corrosion / Wear
•Lockheed Martin-CRADA	Nondisclosure
•General Dynamics-CRADA	Nondisclosure
•NSWC-Dahlgren, VA	Nondisclosure
•John Hopkins Applied Physics Laboratory-MD	Nondisclosure
•University of Maryland-UMBC,MD	Power Electronics

6.2 Research	Application
•Electromagnetic Gun	High Temperature/ Wear Resistant Coatings
•Emerging Materials	Nanomaterials (Nondisclosure)
	Munitions (Nondisclosure)

Cold Spray System Configuration



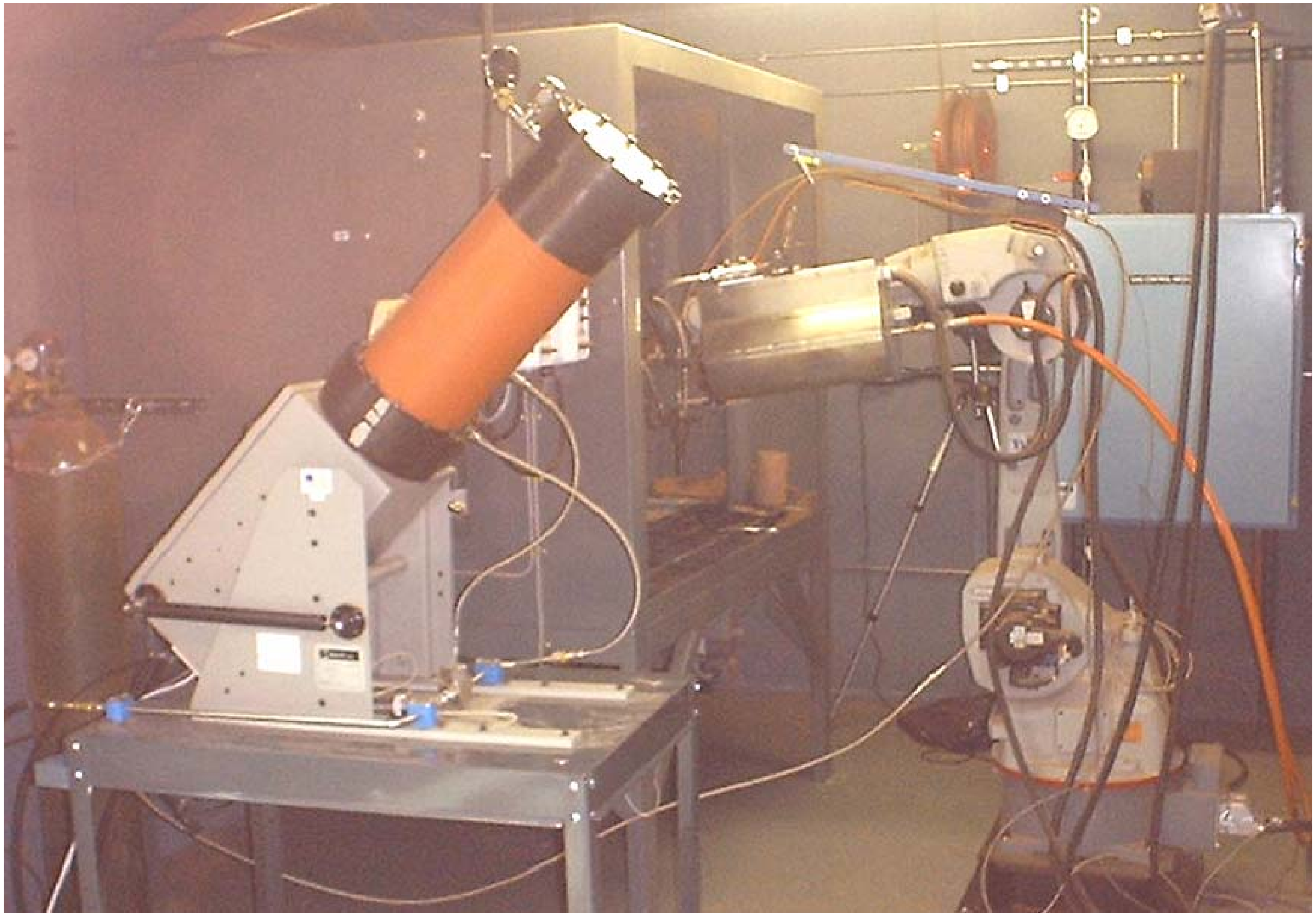
- Main Gas Pressure 100-500 psi
- Gas Temperature 0-1300ºF
- Main Gas Flow Rate 20-60 CFM
- Powder Feed Rate 1 to 10 pounds/hour
- Particle Velocity 300-1500 m/sec.

Stationary Cold Spray System at ARL

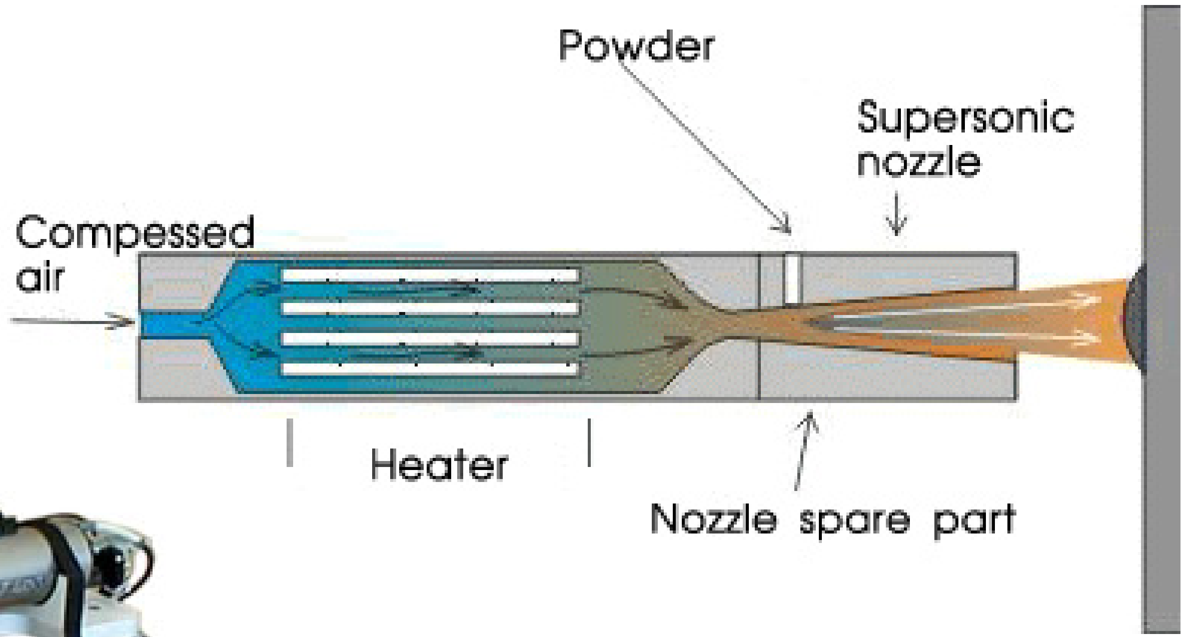
Main Gas Pressure 100-500 psi   Gas Temperature 0-1300ºF   Main Gas Flow Rate 20-60 CFM

Powder Feed Rate 1 to 10 pounds/hour   Particle Velocity 300-1500 m/sec.

Army Research Laboratory SPD System



Portable Cold Spray Systems at ARL



- ➢Hand-Held Heater-Nozzle
- ➢Shop Compressed Air
- ➢Particle Velocity 300-500 m/s

Cold Spray Advantages

Superplastic Particle Agglomerate Mixing (SPAM) bond

- Plastic deformation may disrupt thin oxide surface films to permit bonding
- Similar to explosive welding

Compressive residual stresses

- Particles “peen” surface
- Plasma and wire-arc thermal spray tend to be tensile

High density

- Porosity: < 1 % - 10 %

Thick coatings

- Free-form fabrication up to 1” thick.

EMI Shielding for HMMWV Shelter by Cold Spray

ARL Produces First Prototype Using Cold Spray Technology for the Terminal High Altitude Area Defense (THAAD) Project Office.

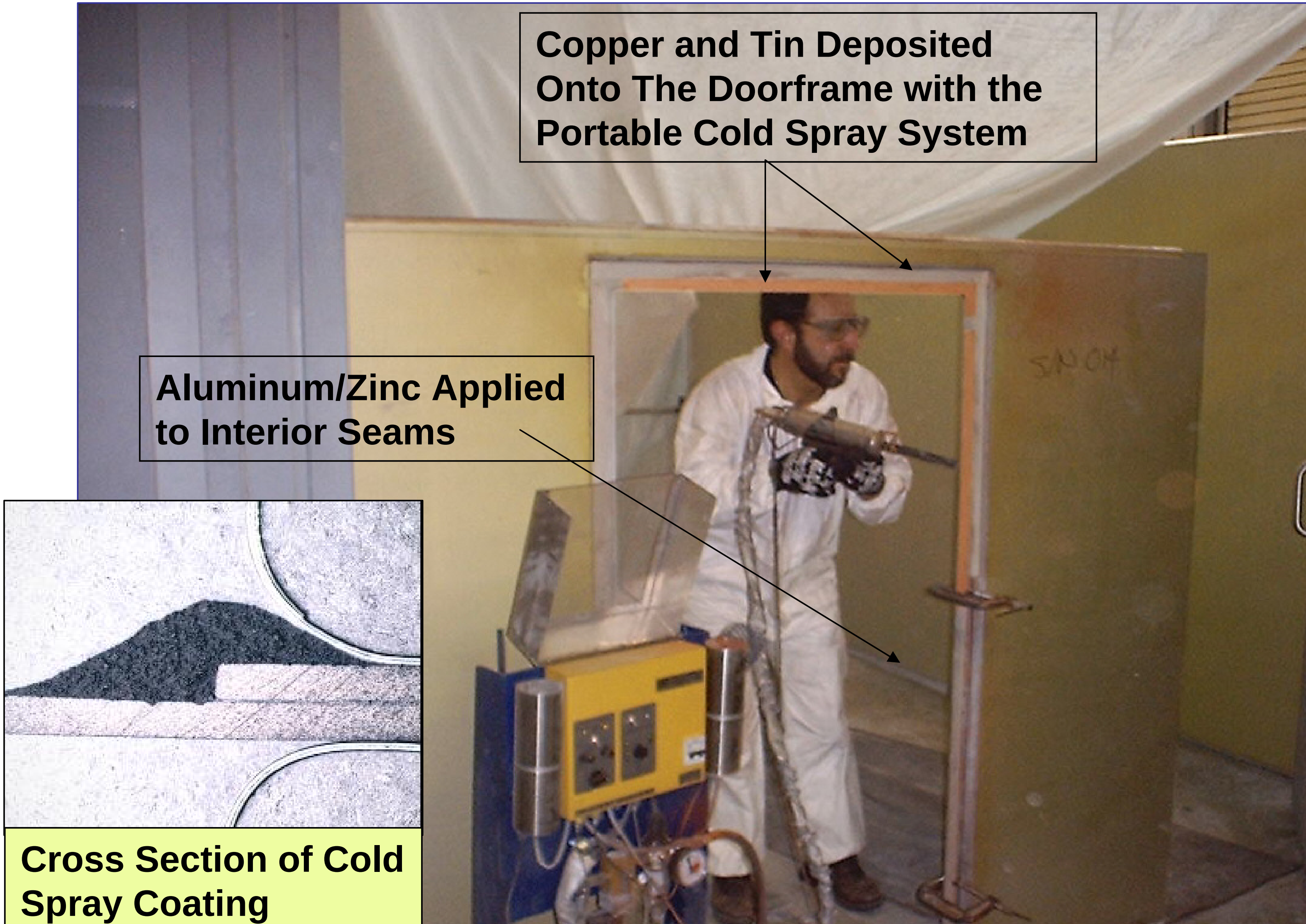
- **HMMWV shelters require EMI shielding to prevent entrance/escape of electronic signals.**
- **The joints in al-composite walls must be sealed with a non-porous, conducting metal.**
- **The composite structure requires low-temperature application of sealer.**

Aluminum

Composite

Conductive material needed to fill seams

Applying EMI Shielding on the HMMWV Shelter

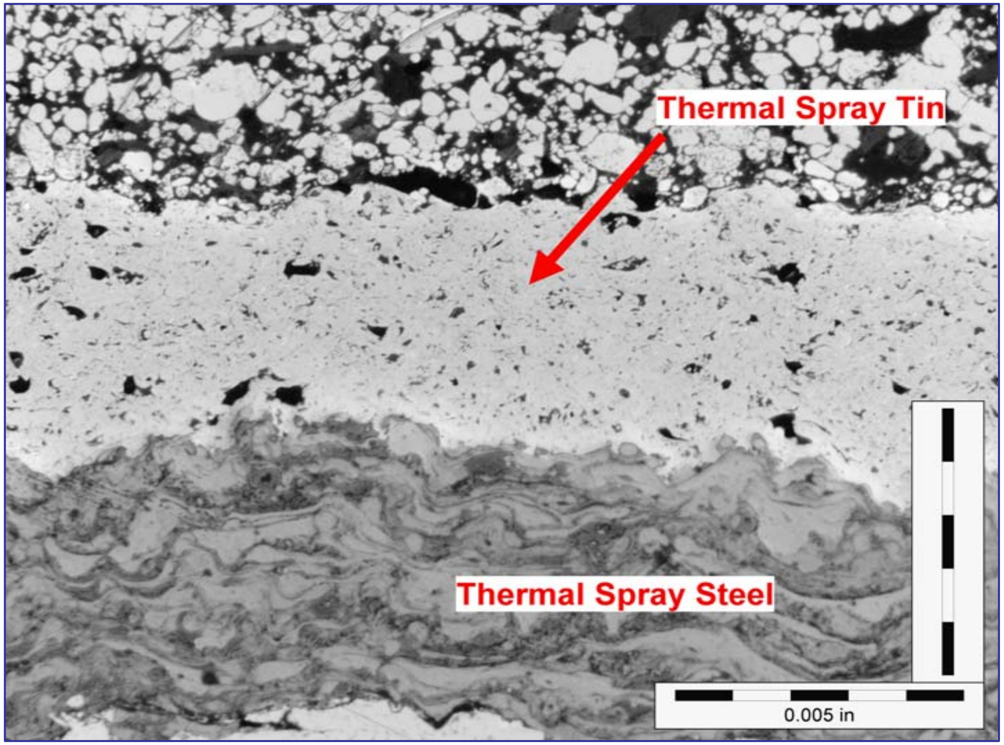


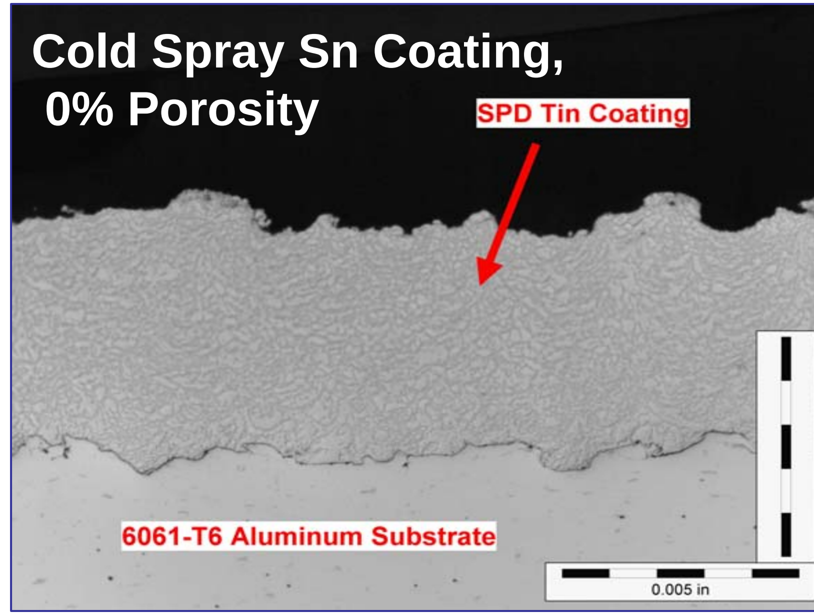
Copper and Tin Deposited Onto The Doorframe with the Portable Cold Spray System

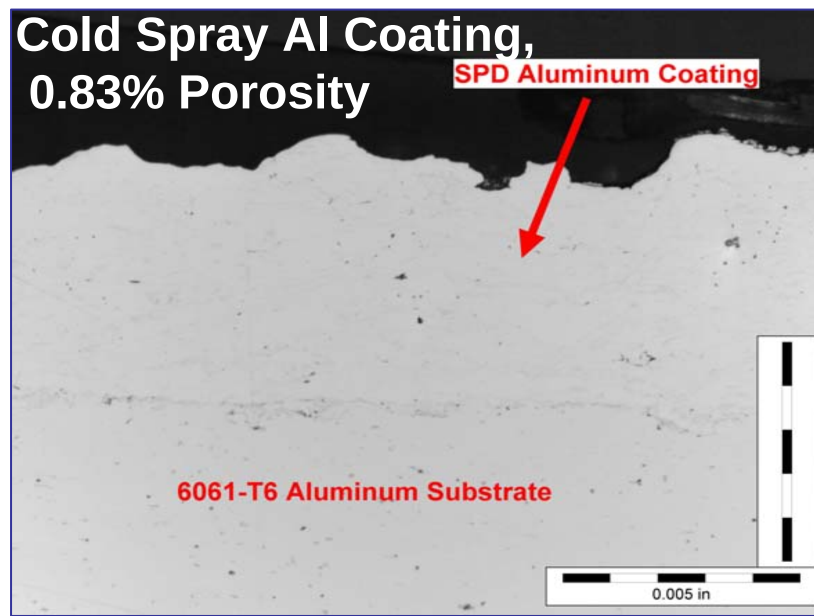
Aluminum/Zinc Applied to Interior Seams

Cross Section of Cold Spray Coating

Comparison of Cold Spray and Thermal Spray







Flame Spray Tin Coating
12.2% Porosity

Cold Spray Technology for Repair of Magnesium Aircraft Components

ESTCP Proposal 06-E-PP3-031

Co-Lead:
Bruce Sartwell
Naval Research Laboratory
Code 6170
4555 Overlook Ave SW
Washington, DC 20375
Phone: 202-767-0722
Fax: 202-767-3321
sartwell@nrl.navy.mil

Co-Lead:
Victor Champagne
Army Research Laboratory
AMSRL-WM-MD
Building 4600
Aberdeen Proving Ground MD 21005
Phone: 410-306-0822
Fax: 410-306-0806
vchampag@arl.army.mil

Use of Magnesium Alloys

- Magnesium alloys used throughout the aircraft industry for gearboxes on helicopter transmissions and gas turbine engines

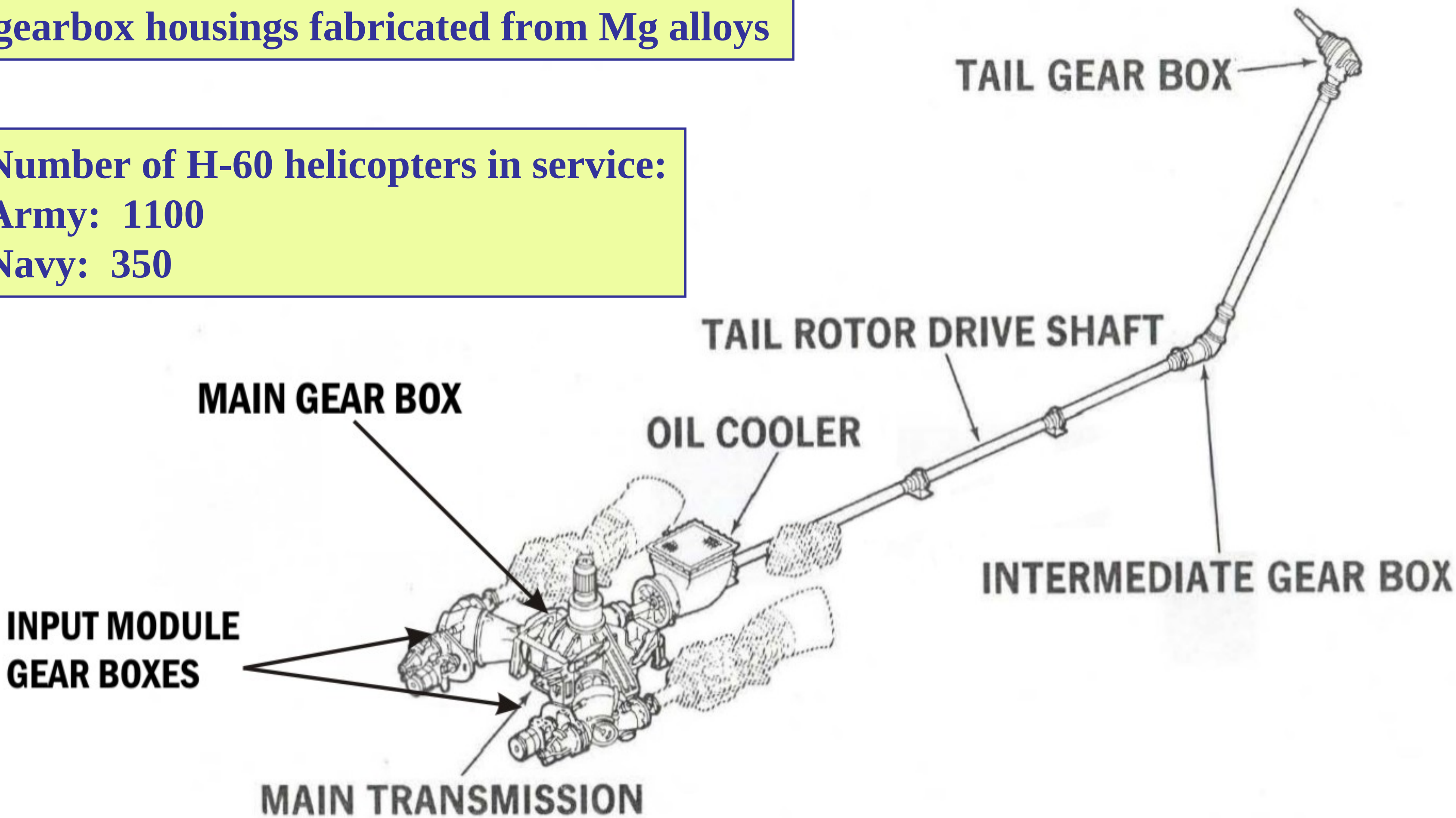
- Use of magnesium alloys expected to increase due to favorable properties:
  - 40% lighter than steel and 20% lighter than aluminum on a like-for-like strength ratio
  - Good damping qualities, absorbing noise and vibration
  - Low density means easier, faster machining of components
  - High thermal conductivity and good EMI shielding
  - Ductile, with ideal casting properties; can be molded into large, thin-walled components at near net shape

- Current usage and future increased usage impacted by high reactivity and susceptibility to corrosion (especially galvanic corrosion); relatively soft and susceptible to scratching; adhesion problems of coatings

H-60 Transmission System Powertrain

All gearbox housings fabricated from Mg alloys

Number of H-60 helicopters in service:
Army: 1100
Navy: 350



U35-213 TRANSMISSION SYSTEM POWERTRAIN

68D4007

Magnesium Alloy Components on Joint Strike Fighter

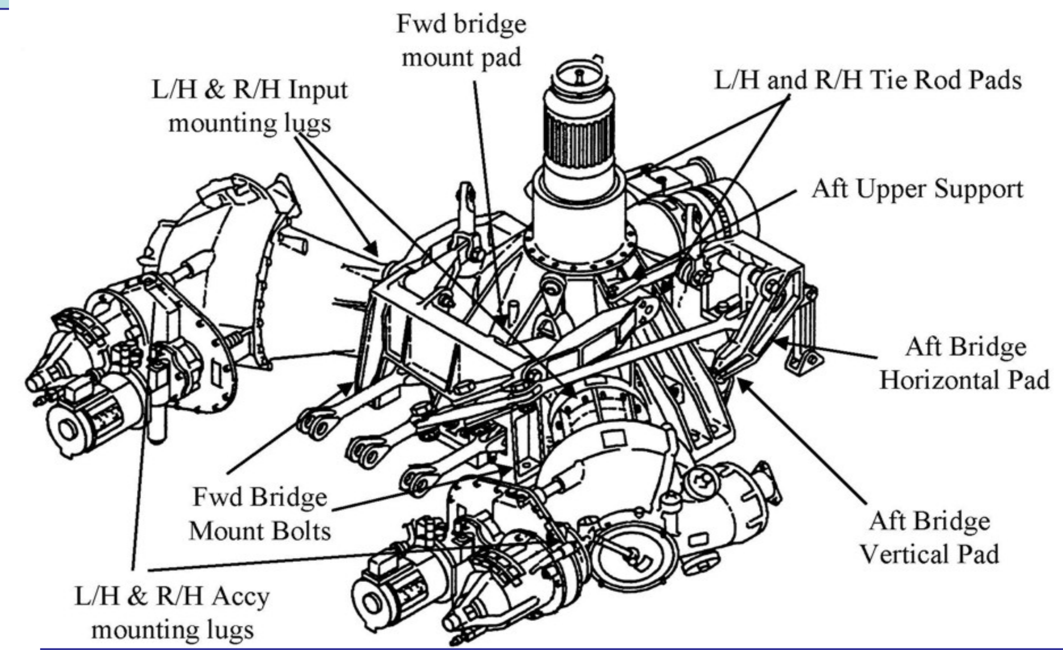
- Four Mg gearboxes in power system
  - Two on engine generator
  - Two on the Integrated Power Package (which supplies all aircraft power when engine not running)

- Dow 17 would normally be used on these components but chromates are on JSF Restricted Materials List; therefore, JSF intends to investigate alternative surface protection processes

Power and Thermal Management System magnesium alloy generator housing

Performance Problems With Current Surface Treatment Methods

- Even with chromated surface treatments, Mg components suffer severe degradation in service
- Most corrosion occurs at mating pads, supports, and mounting lugs where dissimilar metal is in contact with Mg; damage is most likely to occur in those locations as well



H-60 Main Transmission Housing showing areas most susceptible to corrosion

Corrosion on H-53 Tail Gearbox Housing

Requirements for Mg Alloy Components to Address ESOH Issues & Improve Performance

Requirements:

•Alternative method that is ESOH benign for surface anodization of all surfaces to increase corrosion protection and scratch resistance

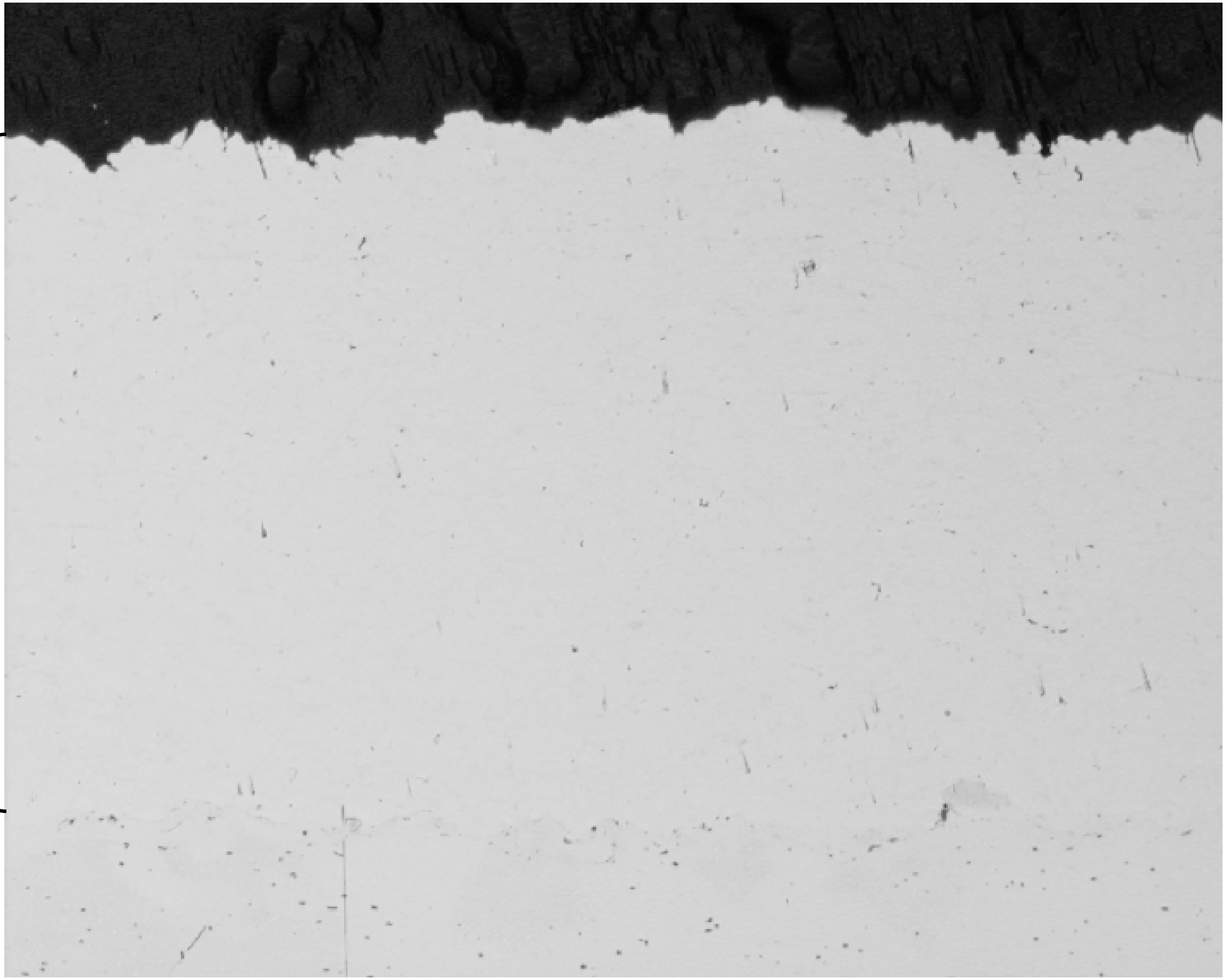
•ESOH-benign method for depositing aluminum coatings in critical areas to enhance corrosion protection and provide for restoration of severely corroded/damaged components; will enable restoration of components currently declared salvage

Solution:

•Plasma electrolytic oxidation (Tagnite or Keronite processes) for anodization is being qualified on components

•Cold Spray of aluminum coatings on critical areas, combined with PEO, will provide TOTAL solution to problem

Pure Al Applied by Cold Spray to ZE 41AMg



Cold Spray
Al Coating
0.015 inch

6,000 psi
adhesion

Expected DOD Benefit

<u>Magnesium Gearbox Housing Repairs at Sikorsky Aircraft Overhaul and Repair Facility</u>

Average Annual Figures

Model	Main	Intermediate	Tail
H-60	275	48	200
H-53	35	20	20

Total of 598 housings repaired

From Sikorsky data, approximately 33% (~ 200) of the housings that go through repair facility must be replaced due to severe corrosion/damage at average cost of $20,000; total annual cost is $4,000,000

Sikorsky engineers estimate that 60% of scrapped housings could be recovered using SPD; deposition of Al onto housings estimated to cost $1500. Therefore, anticipated cost savings is ($20,000 - $1500) x 200 x 0.6 = $2,220,000

ARL Introduces Novel Technology for the EM Gun

ARL completed coating the first two twelve foot long aluminum rails by the Cold Spray technique which tested successfully at IAP in Dayton, Ohio 7-8 June, 2005.

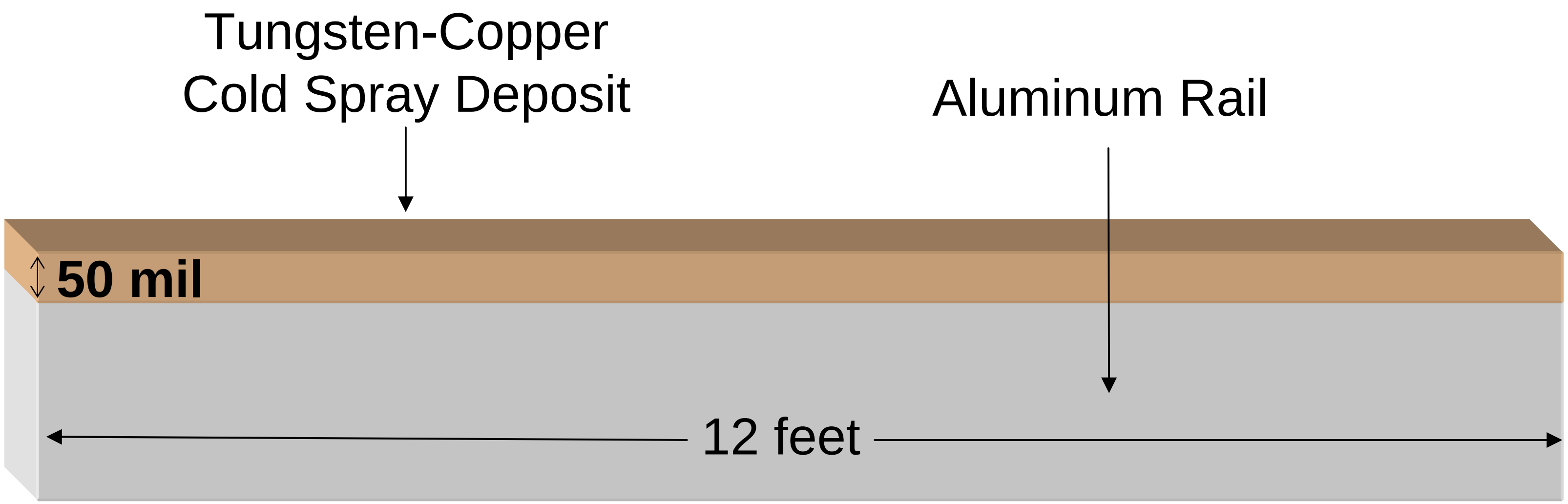
The results of the test indicate that this technology is a major breakthrough, since it is the first time that a coating/liner has been adhered to the rail without failing during actual test firing.

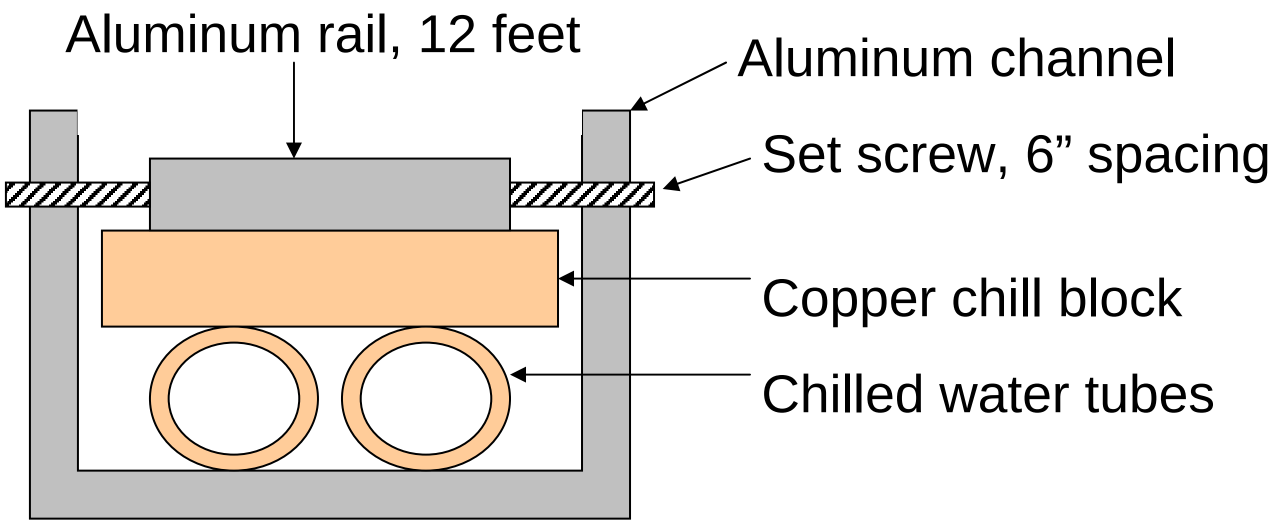
This technique utilizes micron sized particles of metal that are propelled at supersonic velocities onto a substrate to form a coating that becomes part of the substrate, analogous to explosive bonding.

ARL is the only DOD facility to have developed this technology for the EM Gun Rail application.

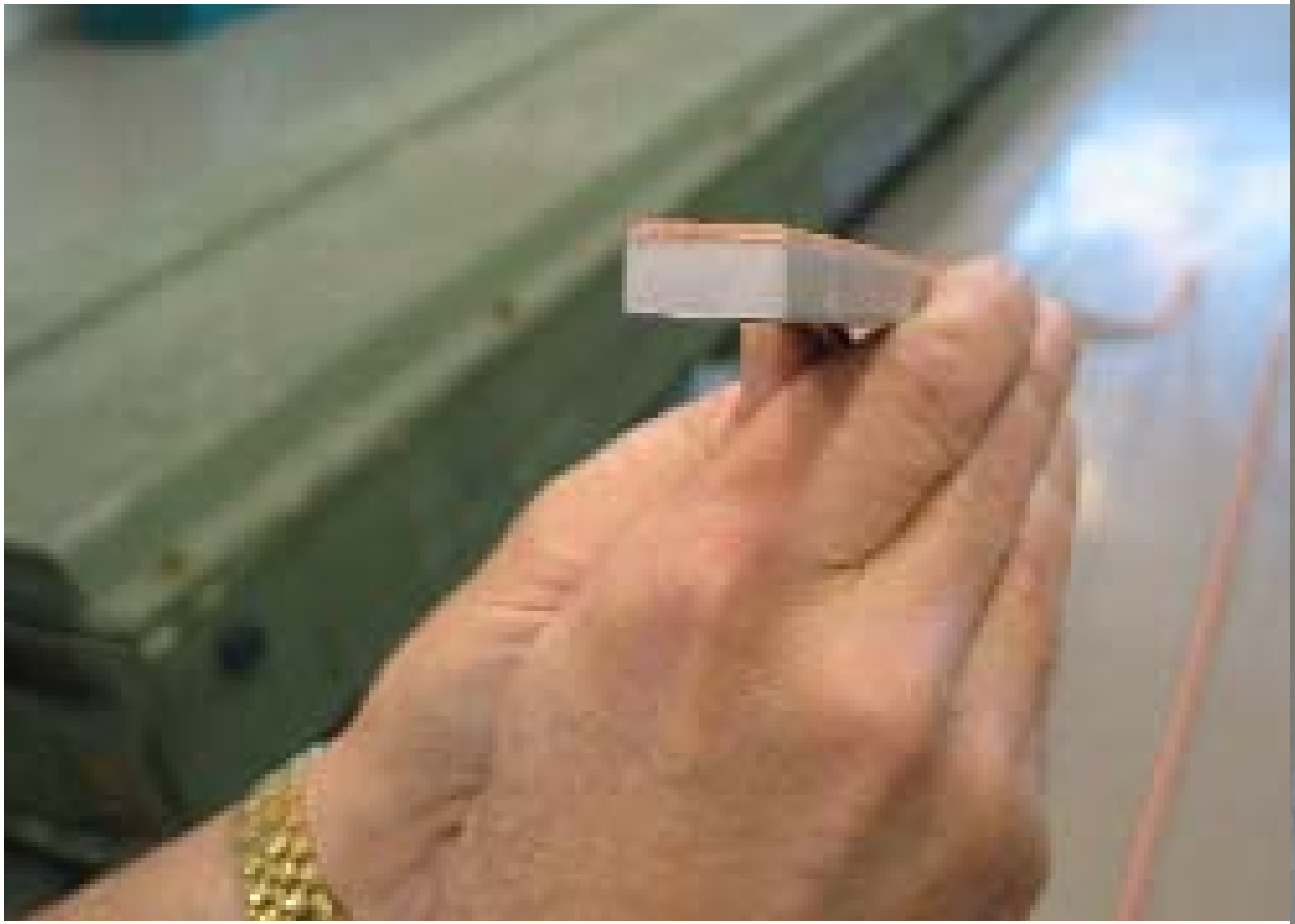
The coating consists of a high concentration of tungsten 70-80% and copper, which results in a hard, wear resistant but very conductive coating.

Apparatus used to Cold Spray W-Cu Coatings





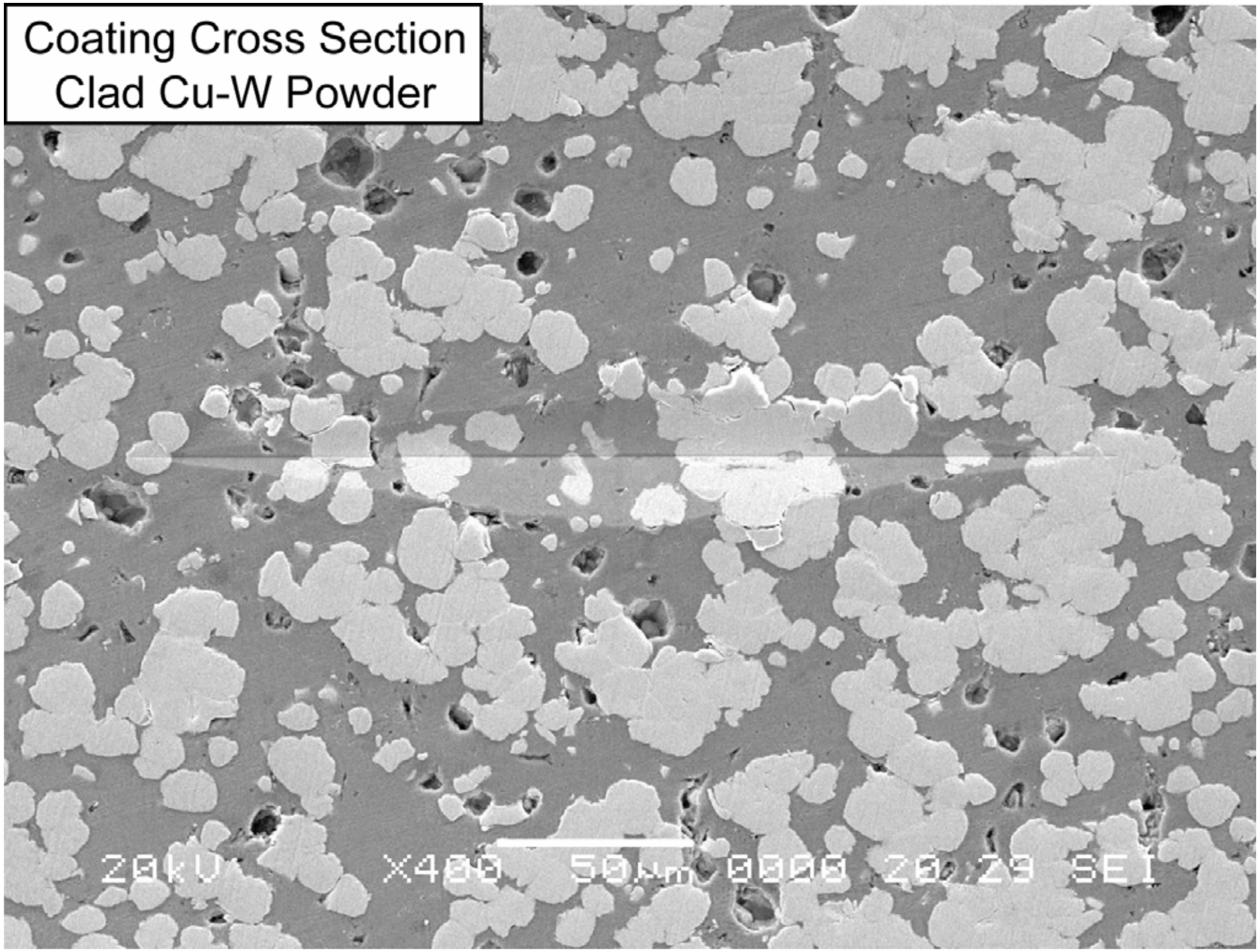
Coated EM Gun Rail by SPD 70%W-30%Cu



Close Up of Cold Coating on 6061-T6511 Aluminum

Front View of Coating

Hardness Indent of W-Cu Cold Spray Coating



- Impression from the Knoop microindenter.
- Demonstrating the ductility of the Cu-W pseudoalloy.
- No cracking is evident.

“The progress of Cold Spray Coatings Technology indeed brought us one step closer for having EM rail guns as a tactical weapon” **Jerome Tzeng**

Ten shots were fired from a 4 meter long laboratory gun at a muzzle velocity range of 2.2 to 2.8 km/s.

The rails were charged up to 480k Amp of current that yielded to a current density of 45k Amp/mm, considered as a high performance rail gun.

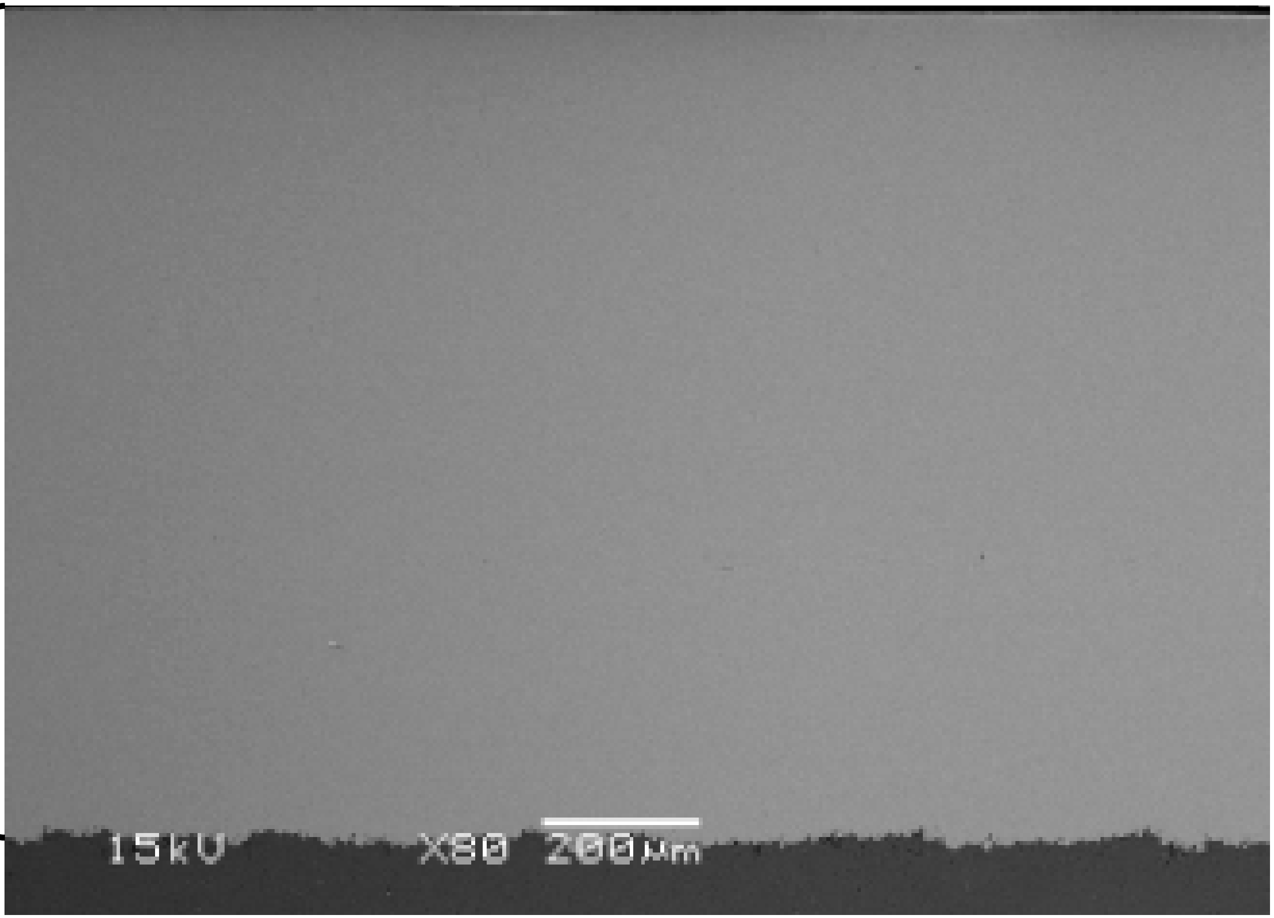
The rail coatings were intact through the very intensive test schedule.

Hardness of Various Cold Spray Coatings

	Knoop Hardness	Equivalent HRB/HRC
Cold Spray Cu-W (powder mixture)	151	75-76 HRB
Cold Spray Cu-W (clad powder)	197	89-90 HRB
Cold Spray Ta	256	21 HRC
Cold Spray Ni	403	40-41 HRC

Cold Spray Coating of Nickel On 6061-T6 Al

Nickel Coating



Hardness of HRC 41 and Adhesive Strength of 10,000 psi

NICKEL COATED EM GUN RAILS TO BE TEST FIRED FEBRUARY 2006

Video of Portable Cold Spray System